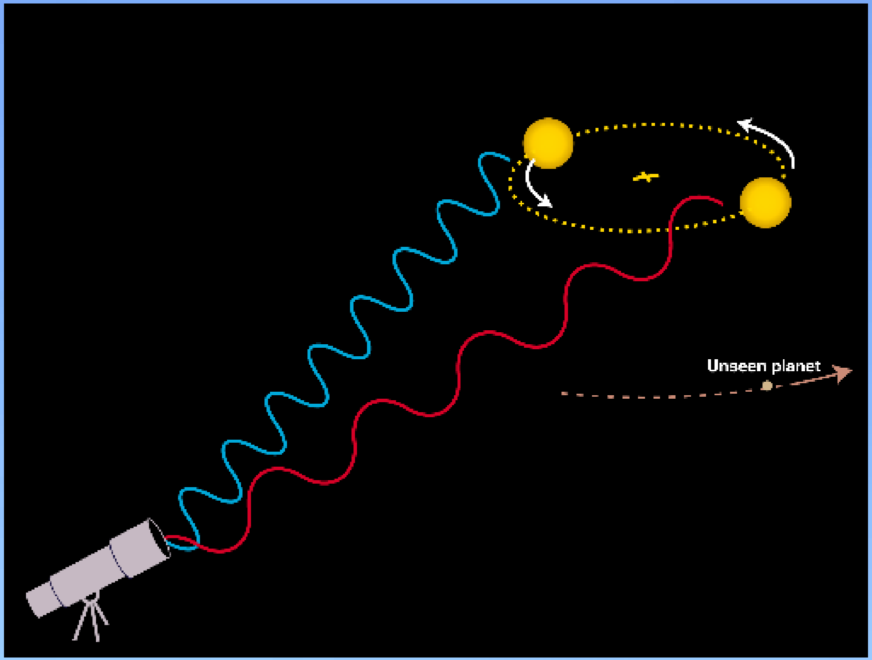
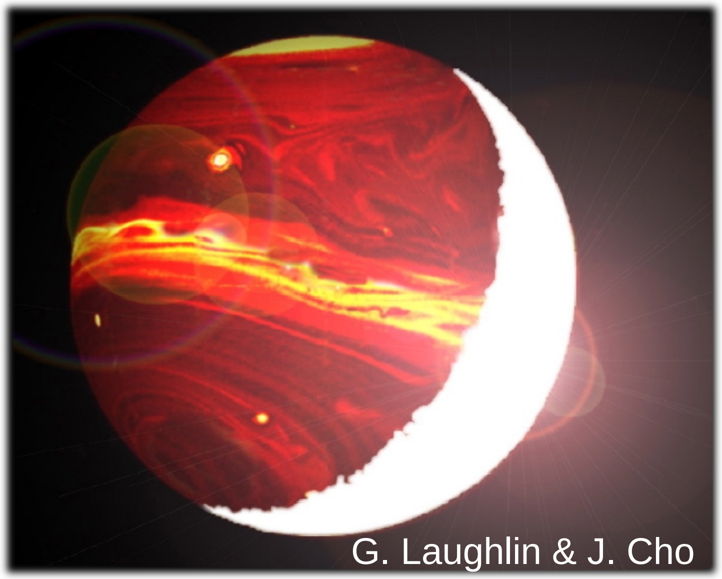
# *Light* from Extrasolar Planets
## *the era of exoplanet characterization*


**Drake Deming**
**NASA's Goddard Space Flight Center**

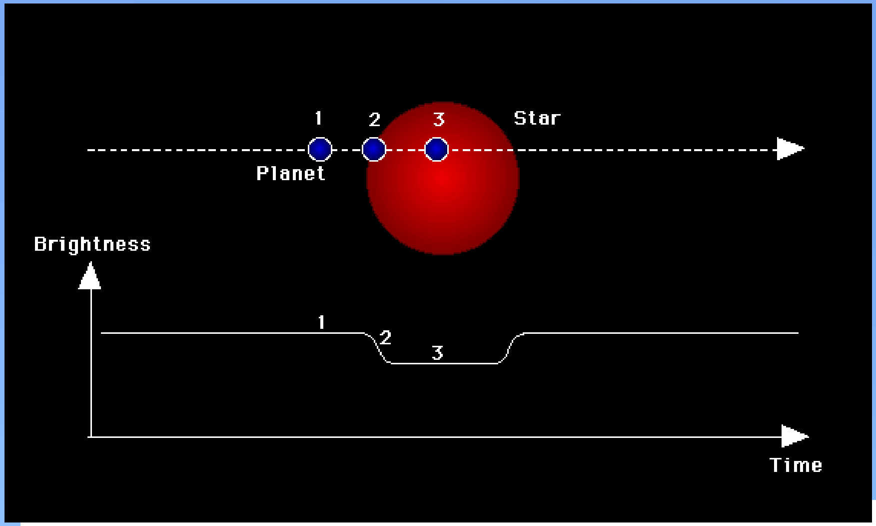

Since 1995, more than 200 extrasolar planets have been discovered - most by radial velocity (indirect detection)

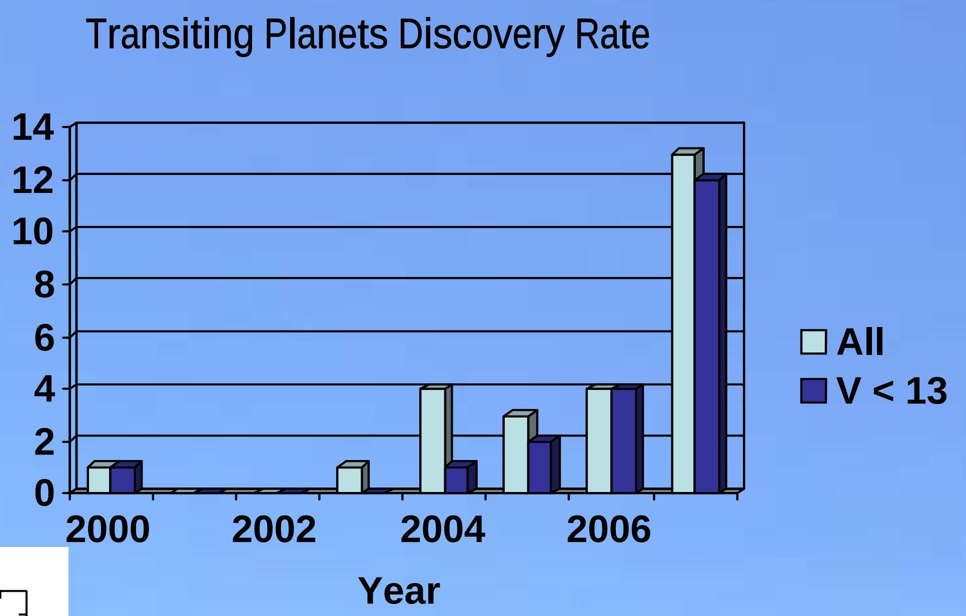


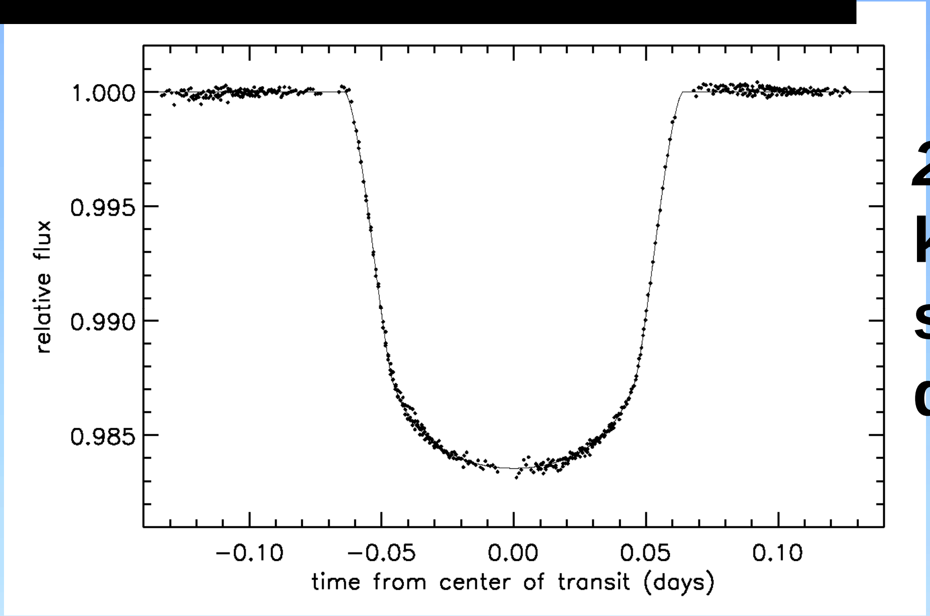




Many of these planets are close to their stars (0.05 AU) - the “hot Jupiters”

# Close-in planets have a high probability to *transit*

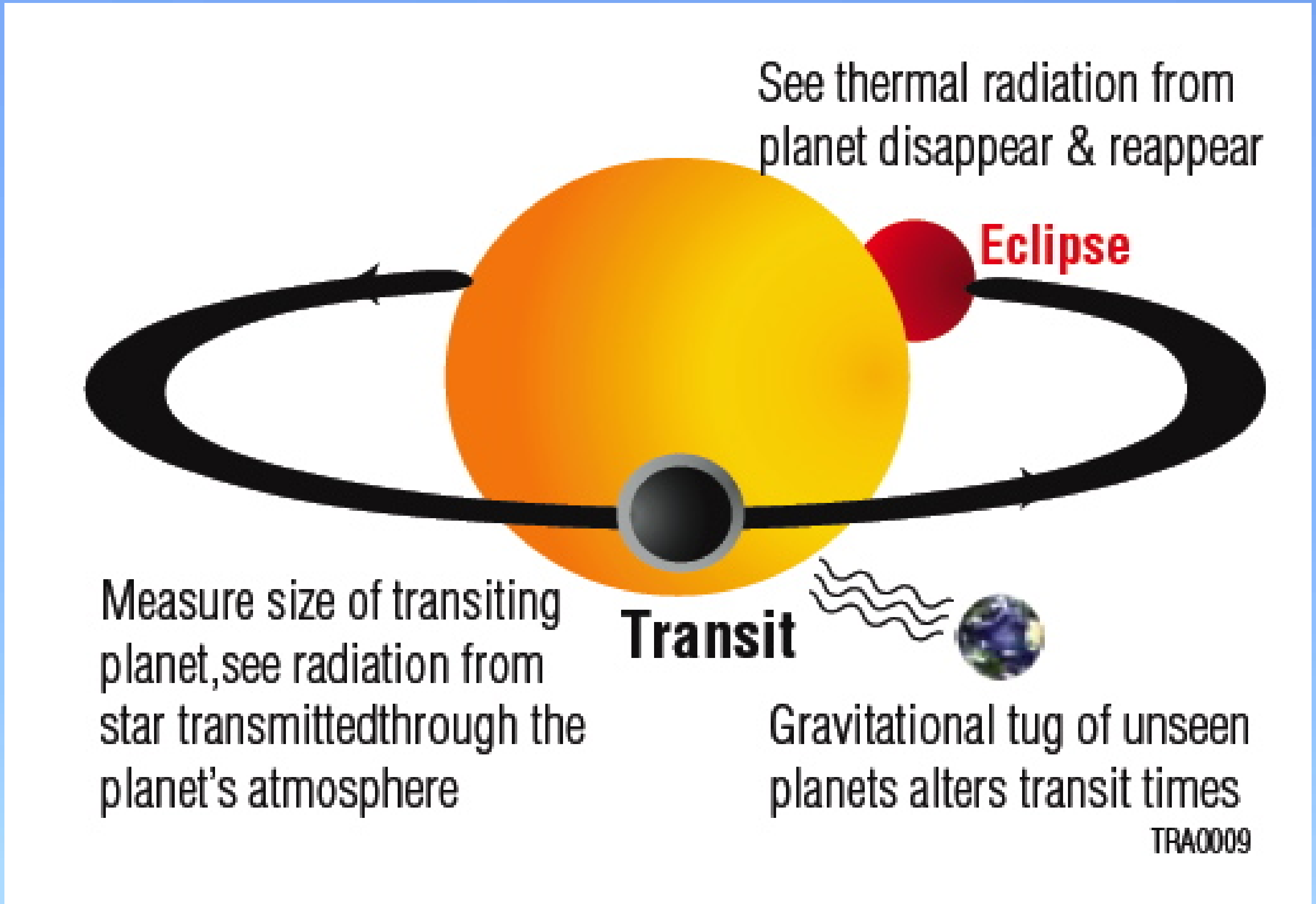


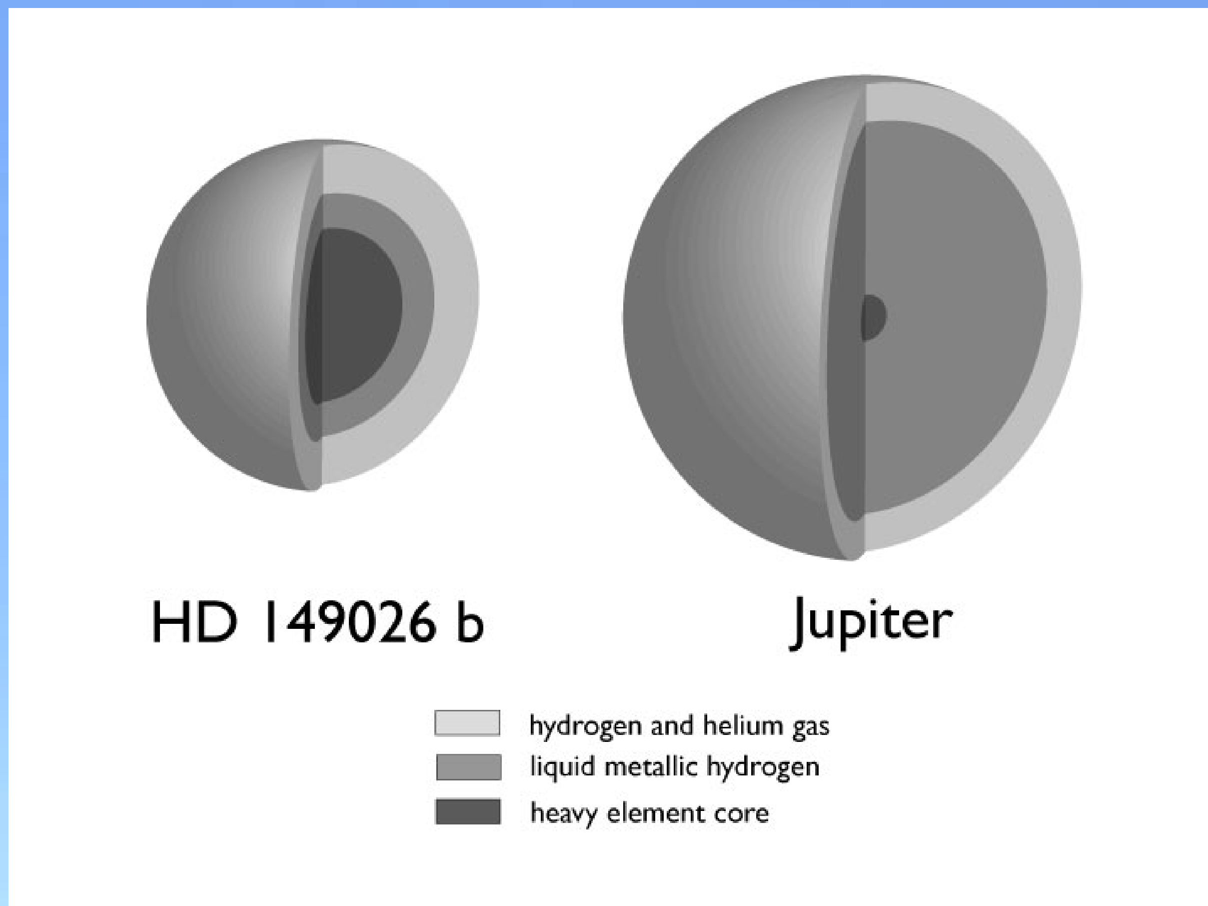

***20*** **exoplanets are now known transiting bright solar-type stars & discovery rate is *accelerating***

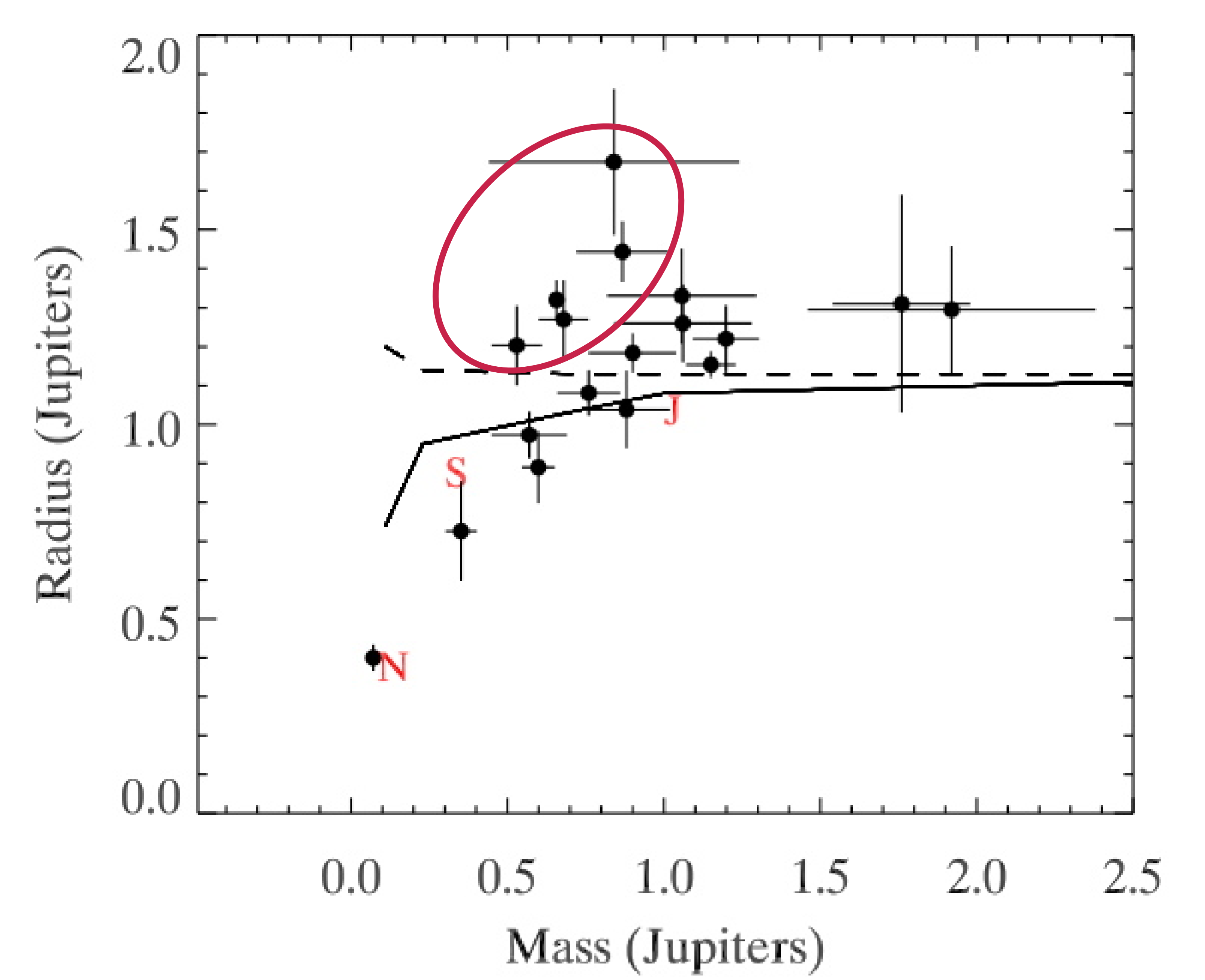
**Transits allow direct physical characterization of the planet....**




**....and detection of currently unseen planets**

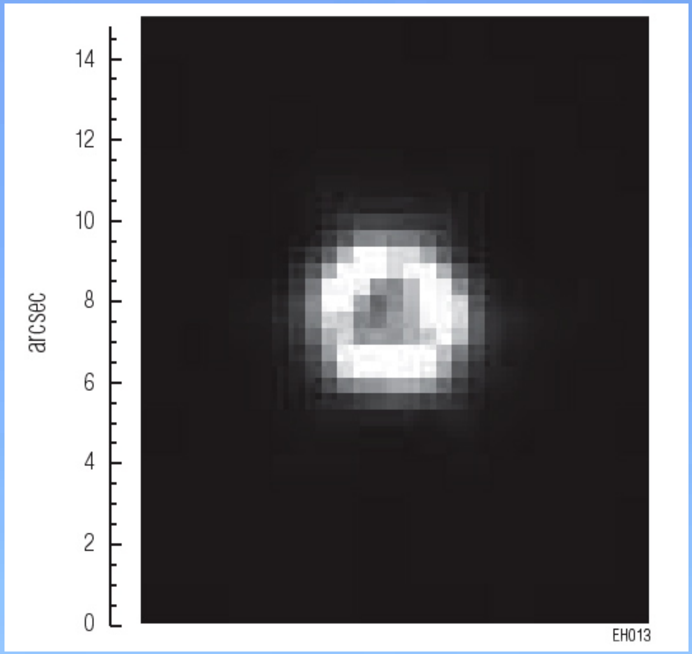
# Mass & Radius from transits inform us of the planet's average interior structure





2.0
1.5
1.0
0.5
0.0
Radius (Jupiters)
0.0
0.5
1.0
1.5
2.0
2.5
Mass (Jupiters)
S
J
N

# EPOXI Transit Science



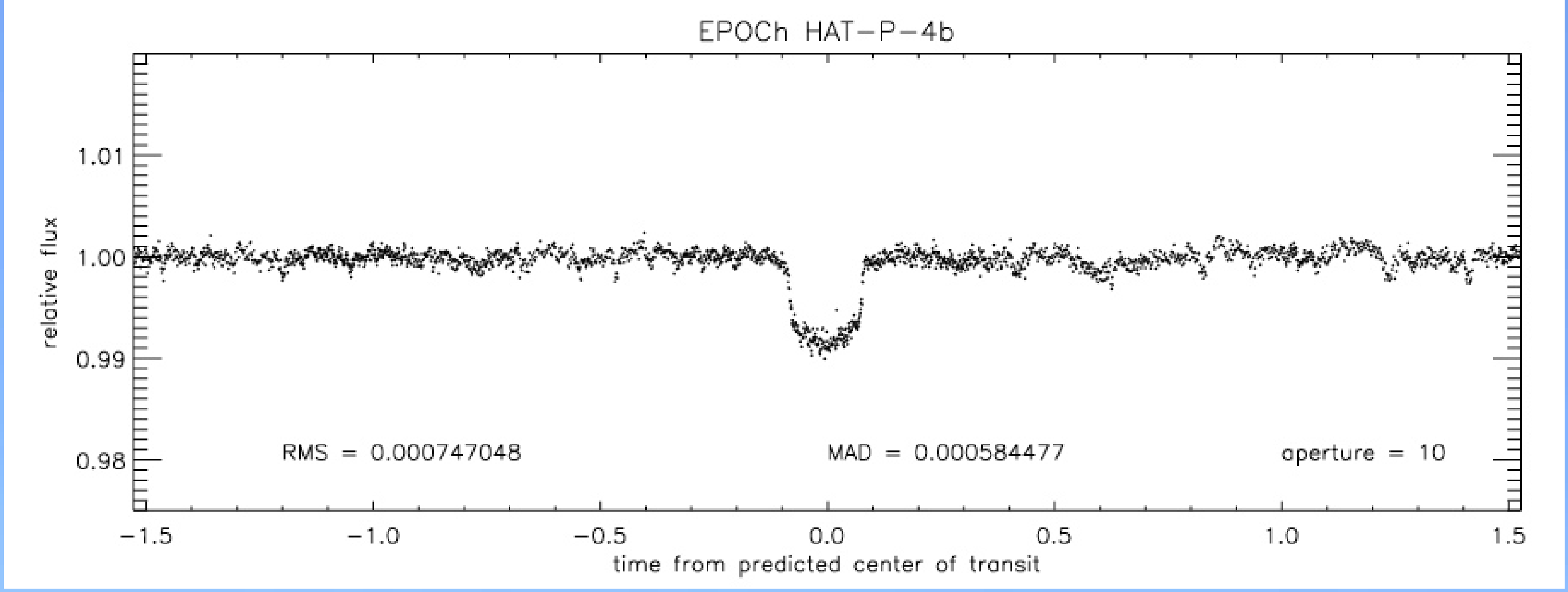

- Photometry using Deep Impact's 30-cm telescope, 350-950 nm band
- Image de-focus & heliocentric orbit facilitate high precision

Observations Jan - May, 2008 (i.e. *now*)
Giant planet transiting systems, bright, and m
not targeted by Kepler

- Reflected light at secondary eclipse
- Search for rings and moons
- Direct search for transits of terrestrial planets (GJ 436 system)
- *Transit timing* search for terrestrial planets

# Preliminary transit of HAT-P-4

**(D. Charbonneau & S. Ballard)**




**Using the CCD calibration from the prime DI mission**

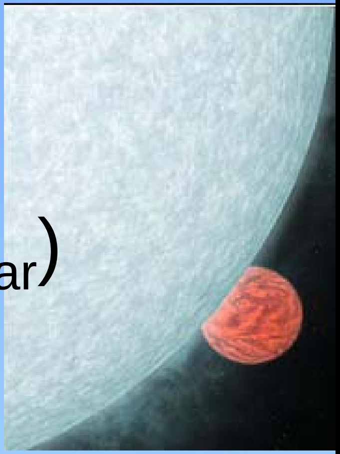
- **new calibration (in hand) will greatly improve the S/N**
- **this is already the most precise transit observed for this system**

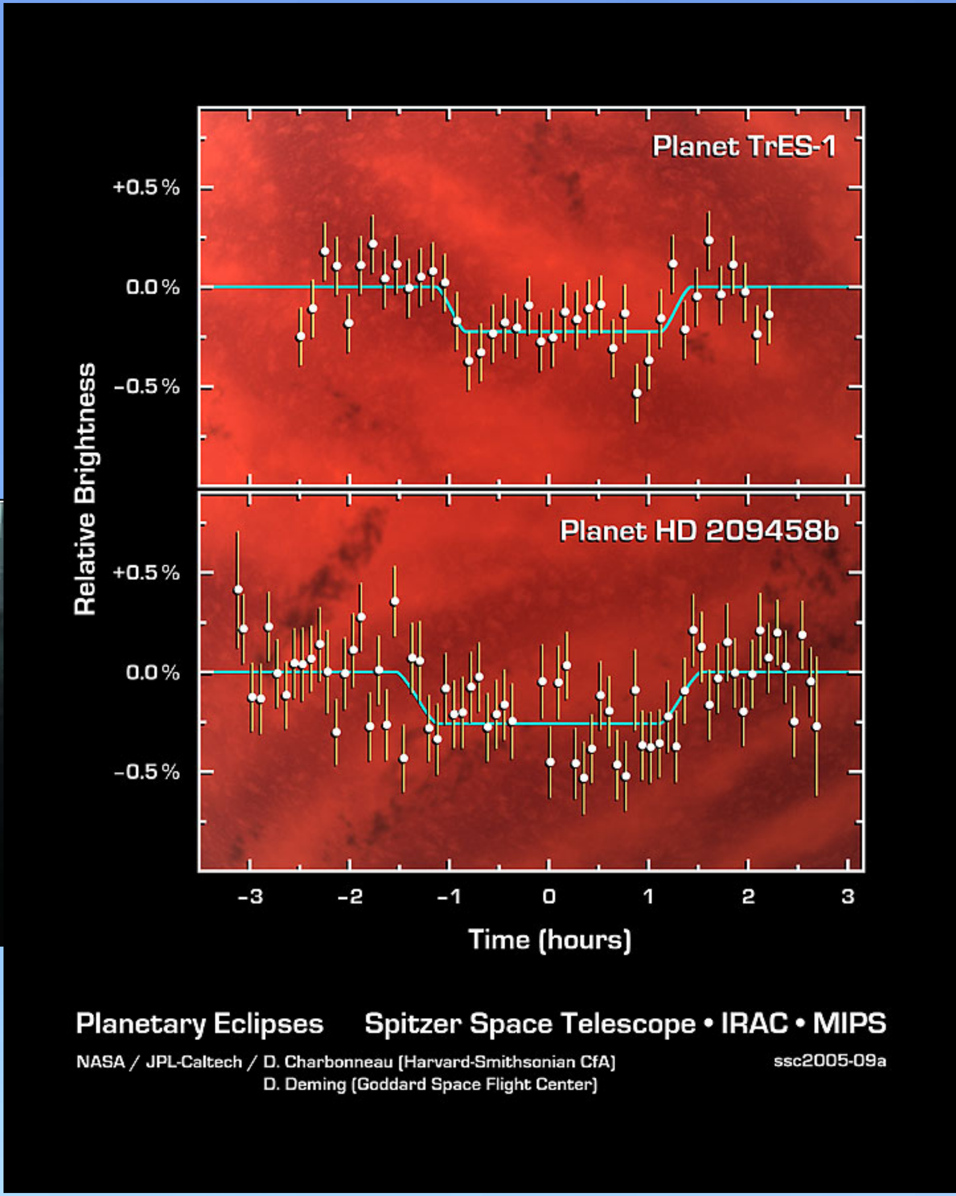
# "First Light" Thermal Emission

Spitzer enables direct detection of IR light from the planets

eclipse depth ~ $(R_p/R_{star})^2(T_p/T_{star})$

yields T ~ 1100K






***Six Spitzer photometric bands can give a low resolution spectrum of the planet***

# Eclipse of HD 189733B

**eclipse depth ~ $(R_p/R_{star})^2(T_p/T_{star})$**

Dominant term

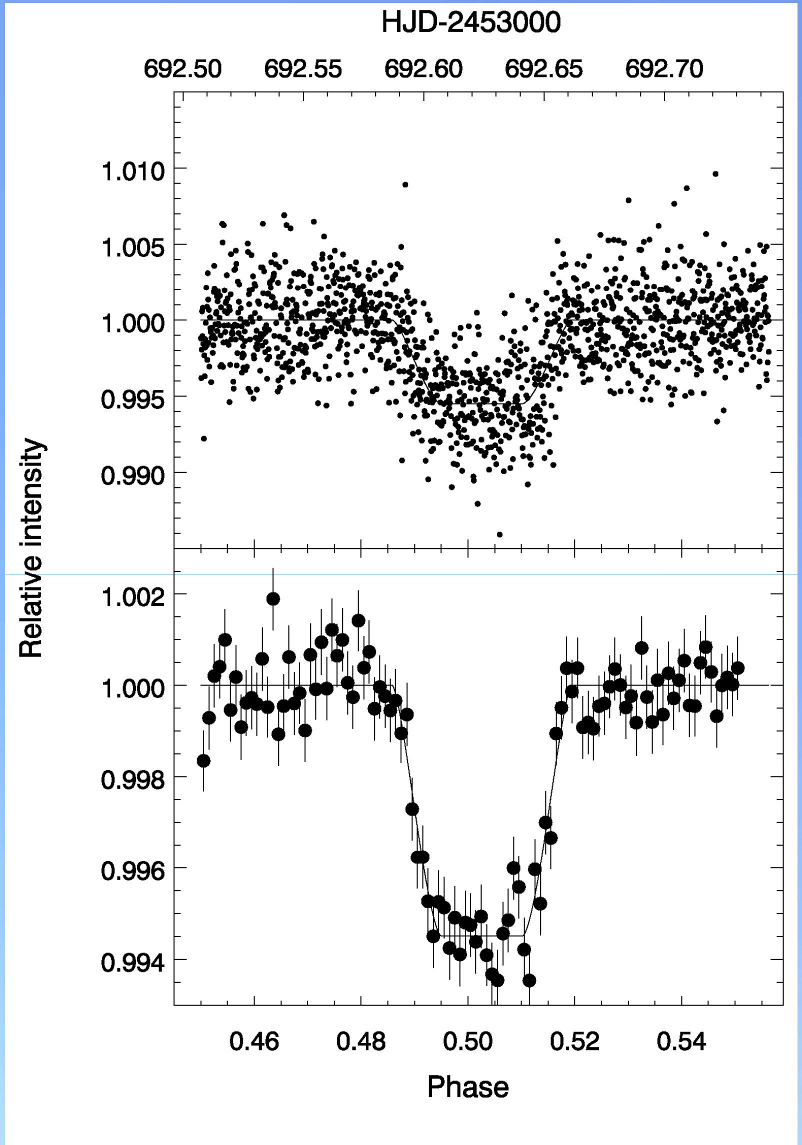
**$T_p \sim T_{star}\, \Delta^{0.5}$**

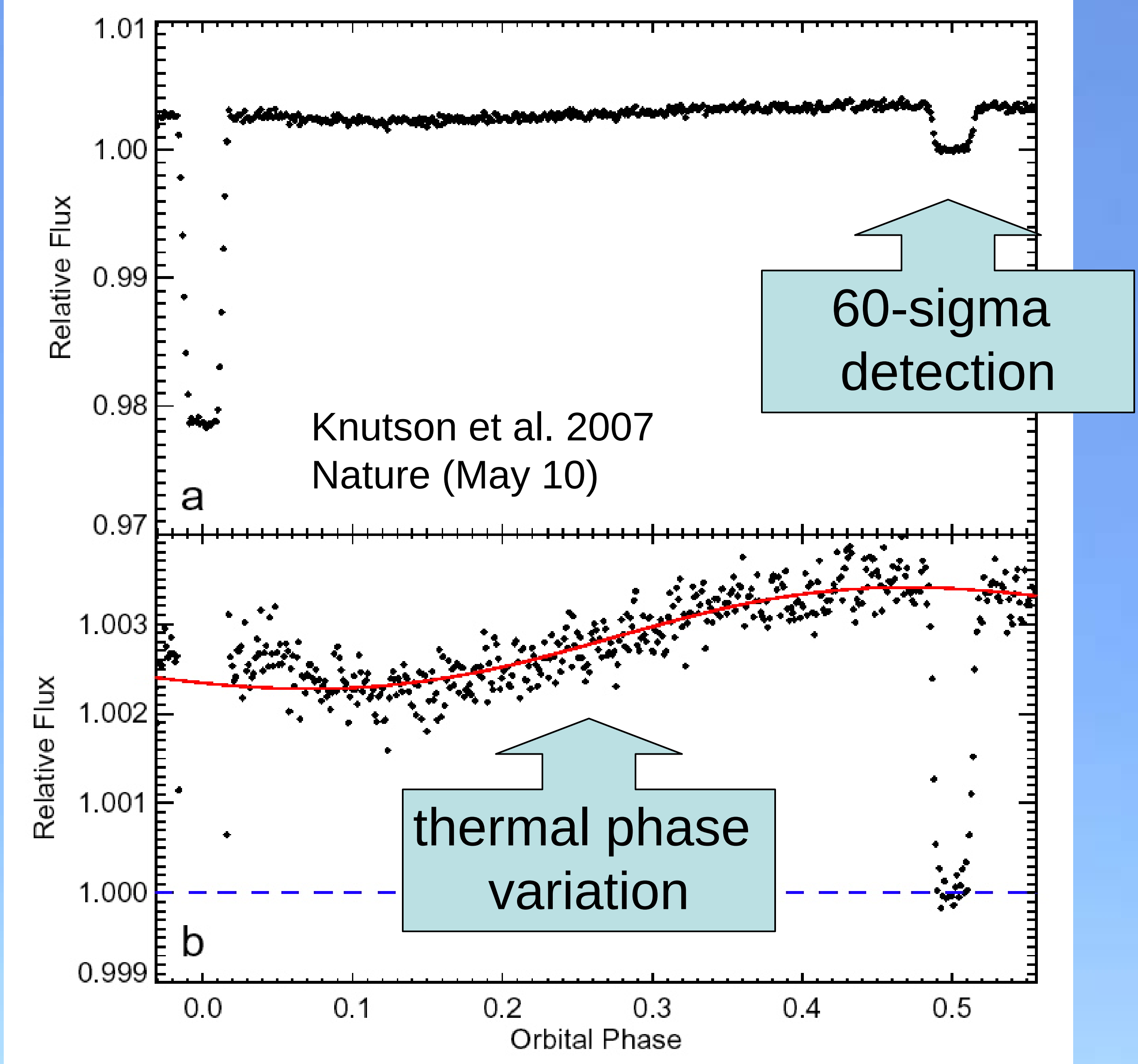
***lower main-sequence stars allow high S/N planet detection***

**HD 189733b (K3V)**

**32σ detection at 16 μm**

Deming et al. 2006, ApJ 644, 560

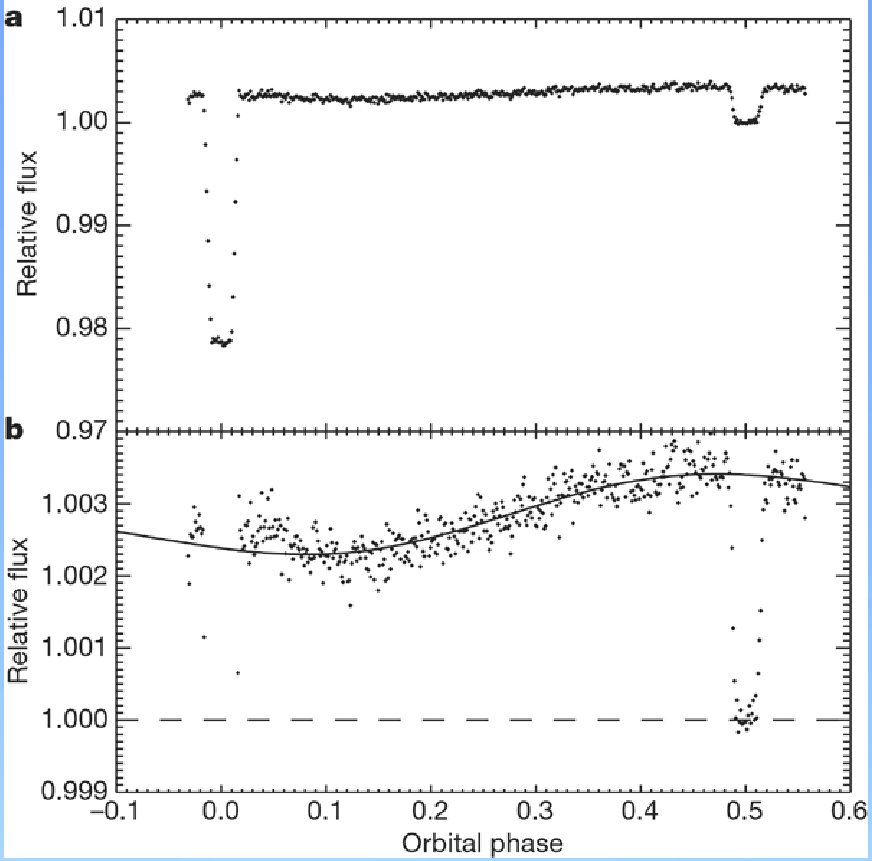


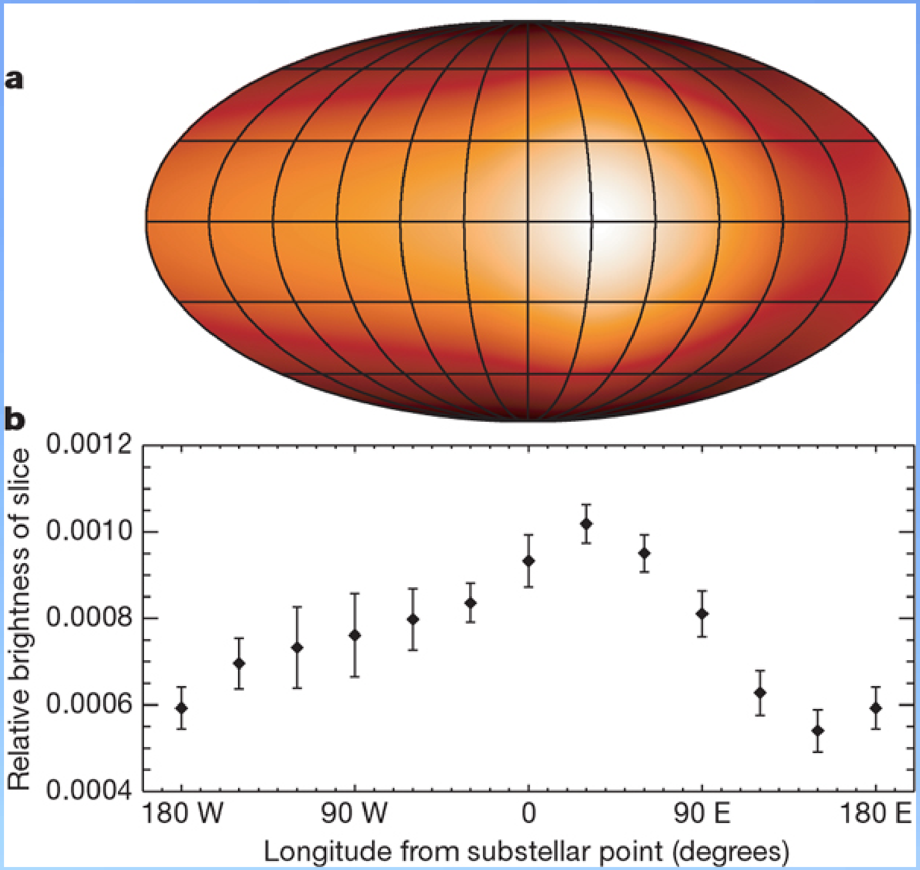

1.01
1.00
0.99
0.98
0.97
Relative Flux
60-sigma detection
Knutson et al. 2007
Nature (May 10)
a
1.003
1.002
1.001
1.000
0.999
Relative Flux
thermal phase variation
b
0.0
0.1
0.2
0.3
0.4
0.5
Orbital Phase

# A Surface Emission Map of an Exoplanet

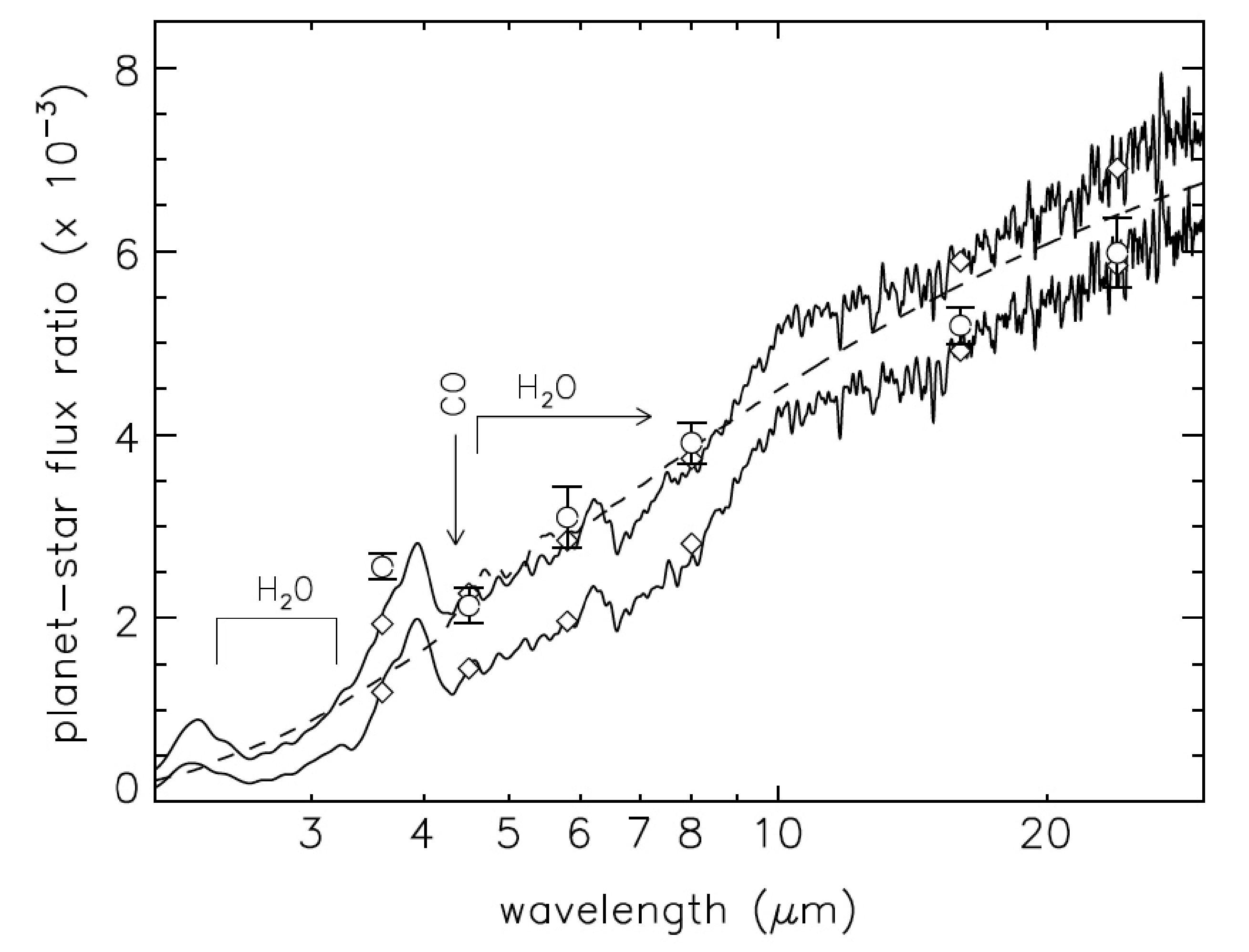
## implies significant redistribution, with a phase lag in longitude (winds)

Knutson, Charbonneau, et al. (2007)



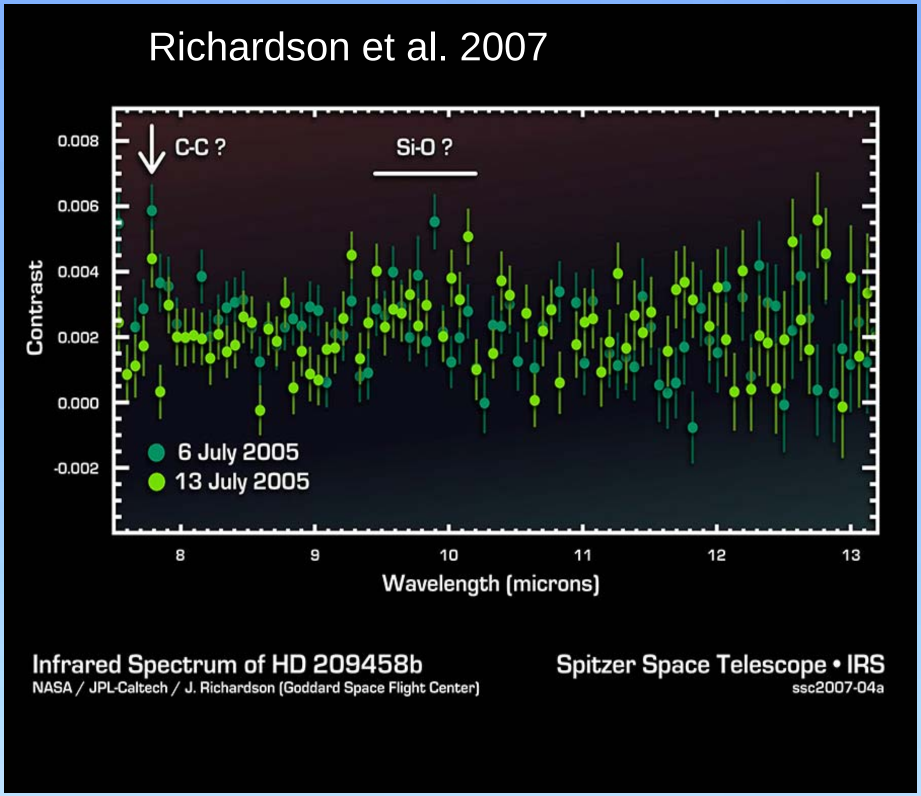
# Energy distribution of HD189733b
# ...a “normal” hot Jupiter

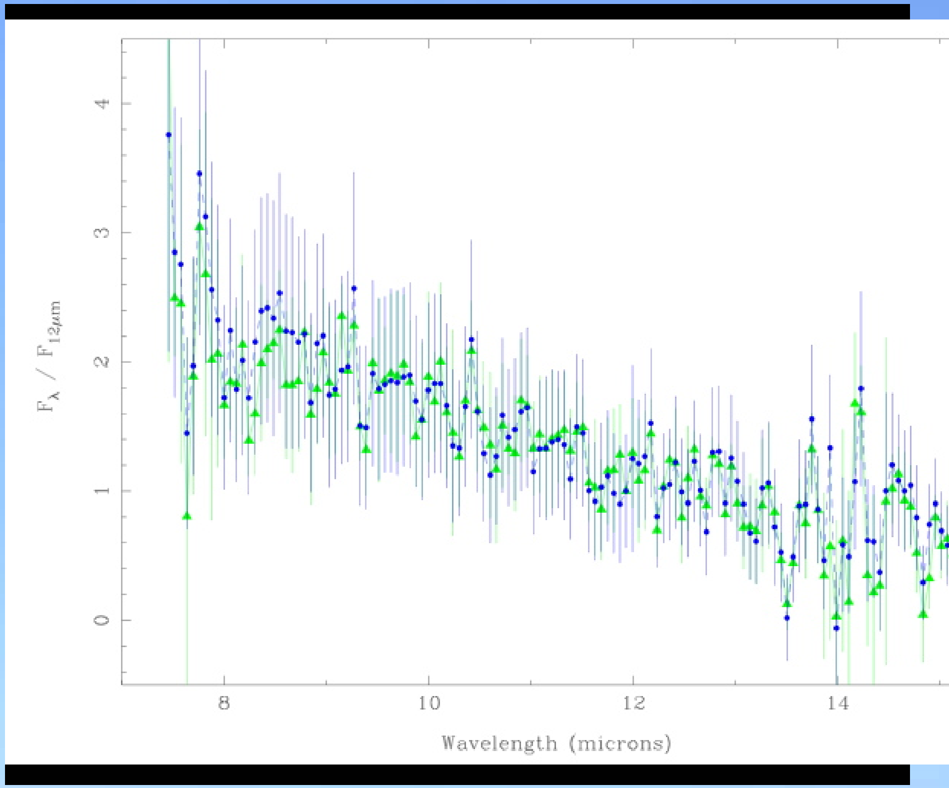


# First Exoplanet Spectra (R ~ 100)

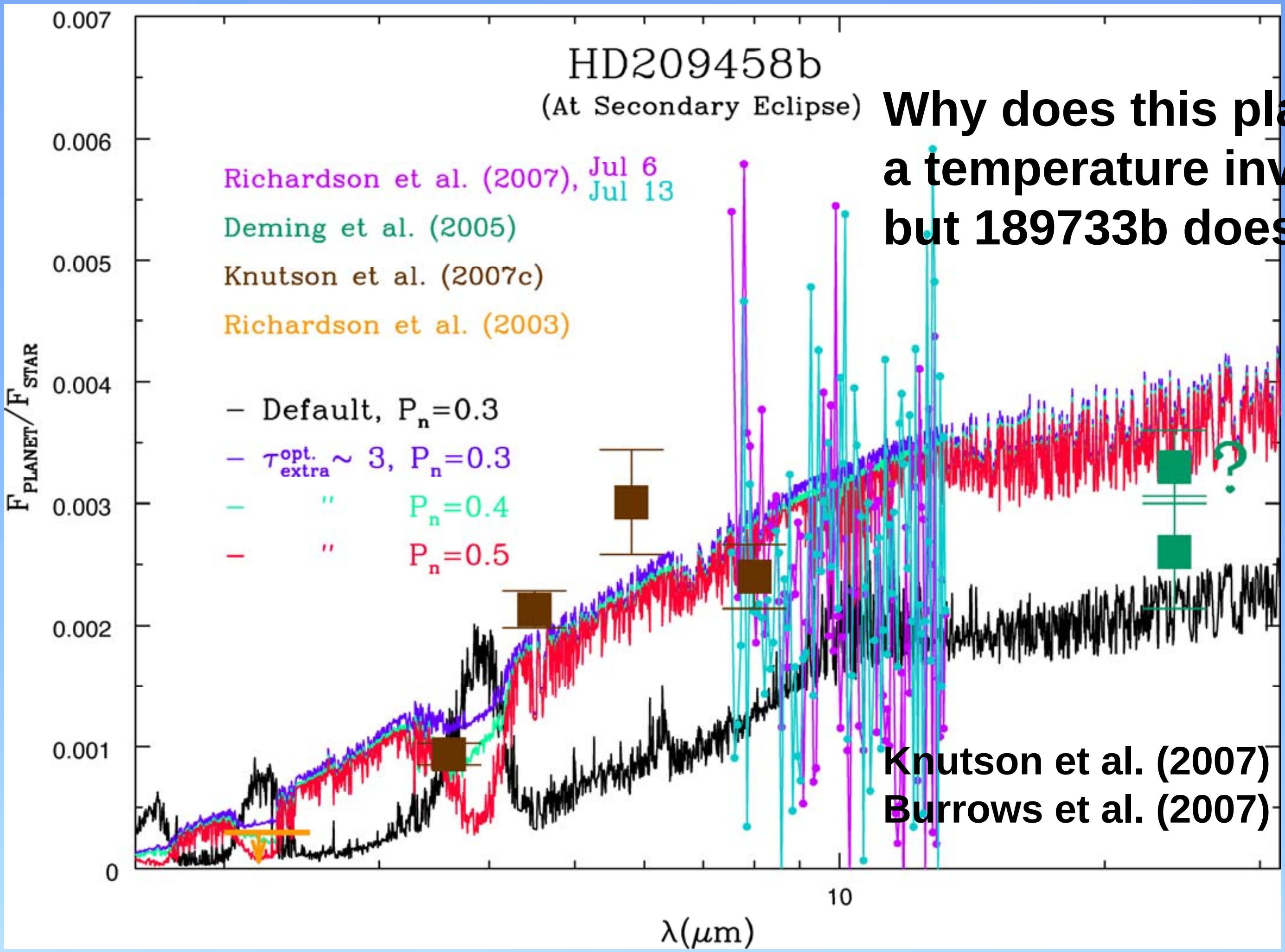
**Planetary emission detected with high confidence, but spectroscopic signature of water is not observed. (But seen during transit by Tinetti et al.)**

**Evidence for emission features in 209458b, consistent with silicates, as well as an unidentified (C-C resonance?) emission feature. Suggests a temperature inversion.**



# A broad-band spectrum (R~5) confirms a temperature inversion in the atmosphere of HD 209458b - water bands invert to emission

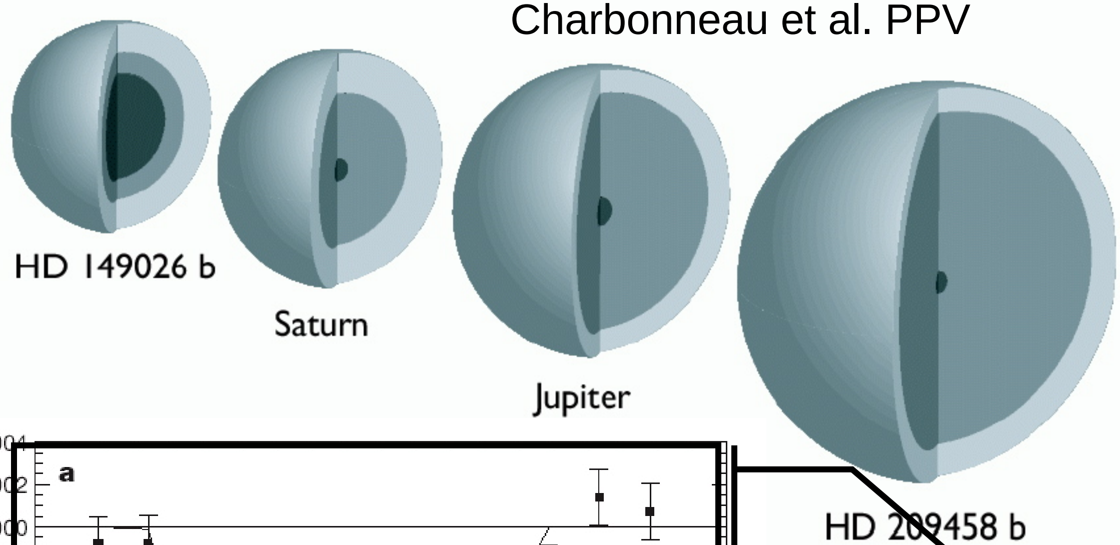


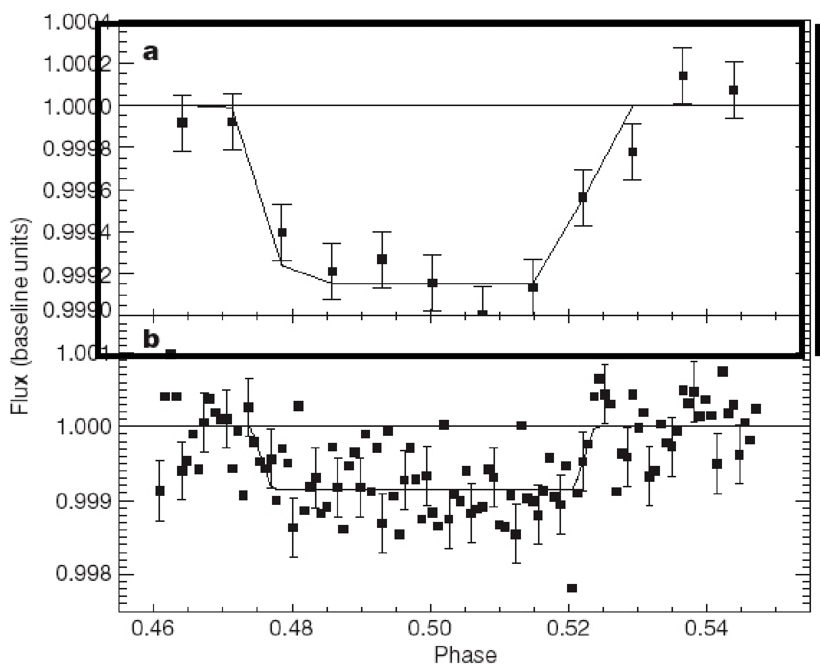

Why does this planet have a temperature inversion, but 189733b does not??

Knutson et al. (2007)
Burrows et al. (2007)

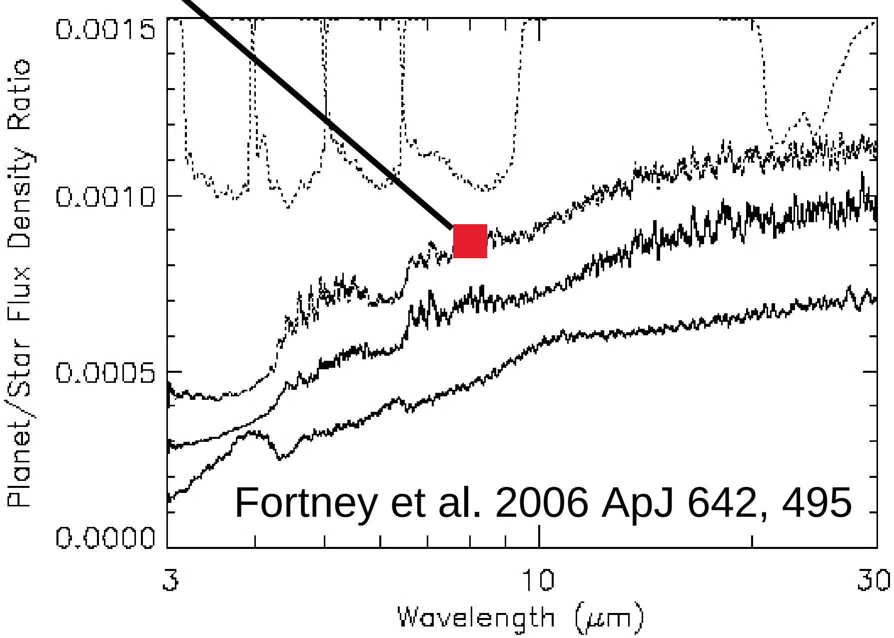
# The Hottest Planet: HD 149026b

Charbonneau et al. PPV



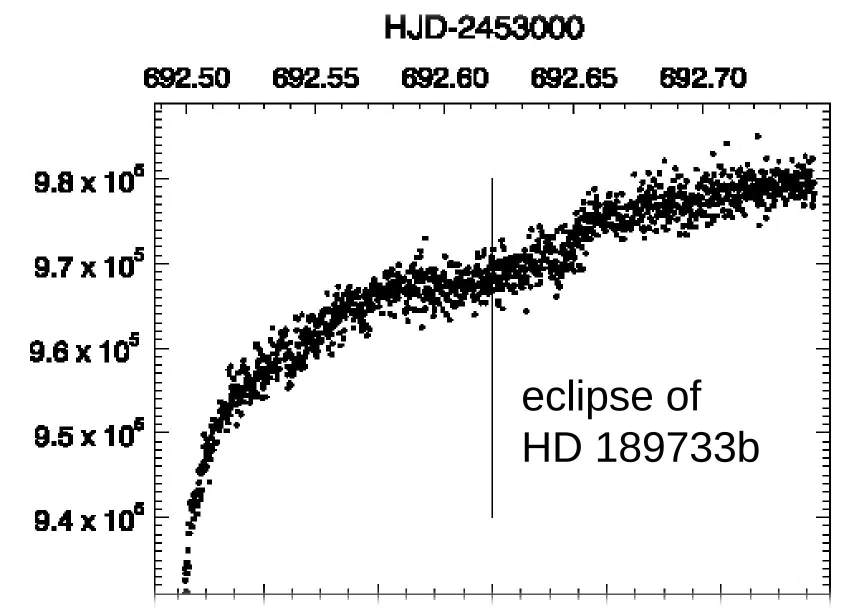

Harrington et al. 2007 Nature 447, 691

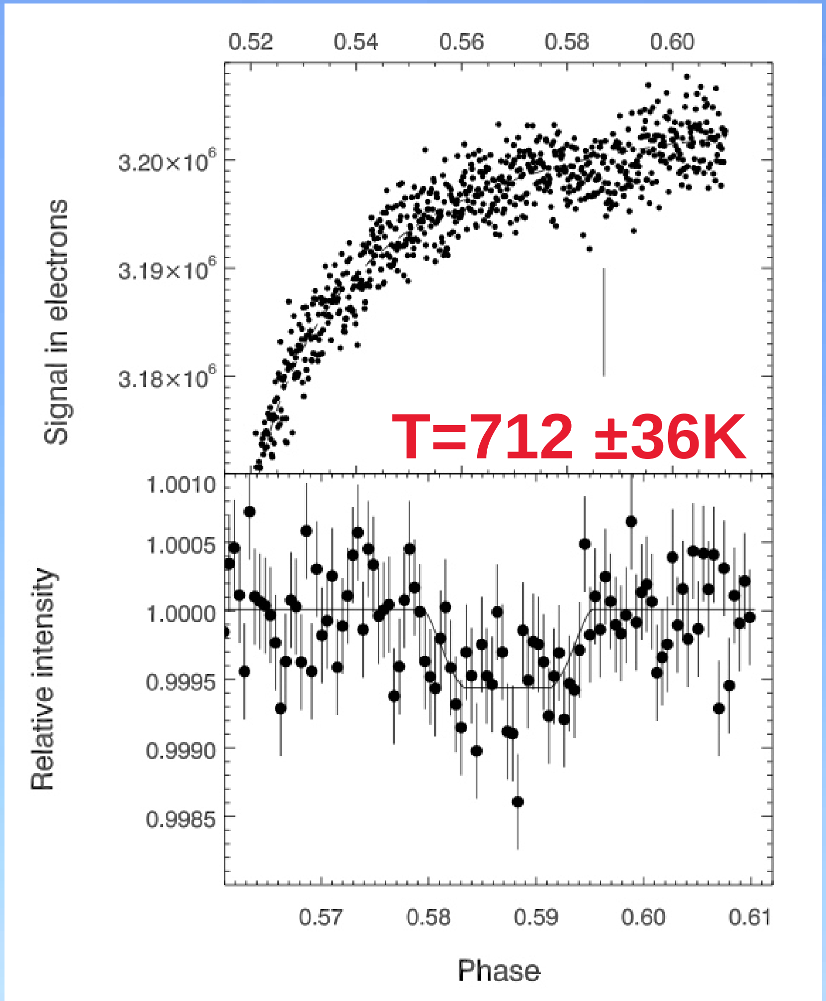



Fortney et al. 2006 ApJ 642, 495

# Secondary eclipse of a *hot Neptune* (GJ436b) orbiting an M-dwarf

(Deming et al. 2007, ApJ 667, L199)



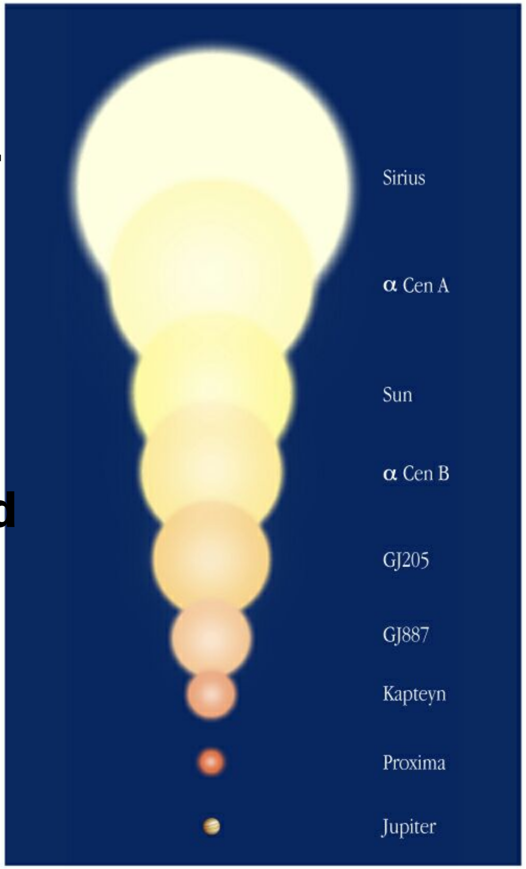



# The M-dwarf Opportunity

**The lowest mass stars (M4V and later) are attractive targets for 3 simple reasons:**

1. **They are VERY numerous (they outnumber Sun-like stars 10:1).**
2. **The habitable zone lies close to the star implying short orbital periods (~10 days) and a higher probability of transits.**
3. **The small stellar size means that rocky planets can be detected with ground-based precision.**

**- D. Charbonneau**



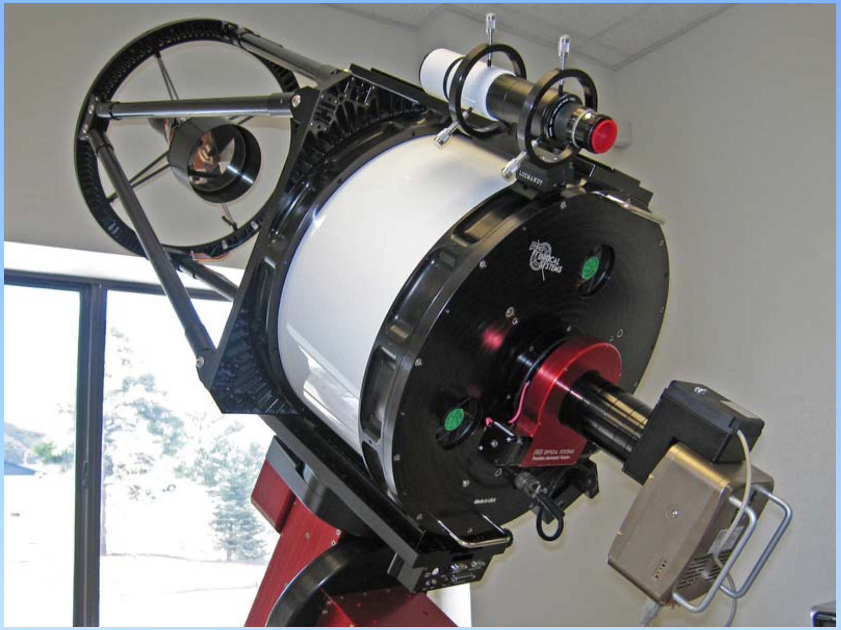

Relative Sizes of the Alpha Centauri Components and Other Objects

ESO PR Photo 07b/03 (15 March 2003)

# The MEarth Project

Charbonneau et al.

- Using 8 X 16-inch telescopes to survey the 2000 nearest M-dwarfs for rocky planets in their habitable zones
- Converted an existing abandoned building on Mt Hopkins, AZ
- 2 telescopes now operational, and 6 more by Jan 2008
- **These planets will be amenable to spectroscopic follow-up to search for atmospheric biomarkers**



# The James Webb Space Telescope

6.5 m diameter
26 $m^2$ collecting area
0.7 - 25 microns

# Summary:

**Spitzer secondary eclipse observations measure thermal emission from hot Jupiters, at R~5 (photometry, ~ 10 planets), and R~100 (two planets)**

**We see dramatic differences in temperature structure. Stellar-related? Planet composition? Photochemistry?**

**Dynamics of heat redistribution also varies**

**Spitzer techniques become more favorable for lower main sequence stars**

- **one M-dwarf hot Neptune being studied using Spitzer**
- **M-dwarf habitable planets will be detectable using future space missions**